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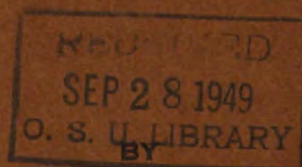
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UNITED STATES
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BUREAU OF MINES
JAMES BOYD, DIRECTOR

INFORMATION CIRCULAR

METHODS AND COSTS OF MINING FLUORSPAR
FROM A FLAT-BEDDED DEPOSIT
AT CAVE-IN-ROCK, ILL.



A. B. NEEDHAM

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By A. B. Needham^{2/}

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^{2/} Mining engineer, U. S. Bureau of Mines.

INTRODUCTION

This paper, which describes mining practices at a mine in the Cave-in-Rock, Illinois, fluorspar district, is one of a series being prepared by the Bureau of Mines on mining practices, methods, and costs in the various mining districts of the United States.

Ore deposits in the southern Illinois-western Kentucky fluorspar district are of two general types - (1) the flat-bedded, lenticular replacement and (2) the relatively narrow, rather steeply dipping fault or fissure filling. This paper describes production methods used and results obtained in mining one of the bedded lenticular ore bodies that are prevalent in the northeast portion of the district near Cave-in-Rock.

ACKNOWLEDGMENTS

Acknowledgment is made to the management of the Minerva Oil Co., St. Louis, Mo., for permission to present the data that follow; also to J. H. Steinmesch and Gill Montgomery, Eldorado, Ill., general manager and superintendent, respectively, who furnished much of the information presented. Special acknowledgment is due Floyd Callahan, mine superintendent, and C. W. Shaw, engineer, who gave freely of their time for underground inspections and of their knowledge of operations.

HISTORY

The Minerva Oil Co.'s mine No. 1 is in the NW 1/4, SE 1/4 of sec. 24, T. 11 S., R. 9 E., Hardin County, Ill. about 5-1/2 miles north of Cave-in-Rock (fig. 1). Its brief history goes back to only 1939; therefore, it is one of the youngest large producers in the Illinois-Kentucky district. Late in 1930, the Mahoning Mining Co., by extensive drilling, disclosed a flat-dipping lead-zinc-fluorspar ore body in the NE 1/4 of sec. 34, T. 11 S., R. 9 E. The Minerva Oil Co. believed there might be a northeast extension of that mineralization and accordingly, in 1939, optioned considerable land in sections 23, 24, 25, and 26, T. 11 S., R. 9 E., and in sections 18, 19, and 30, T. 11 S., R. 10 E. With sparse outcrop showings of the fracture trends for guidance, drilling was begun and eventually disclosed a substantial tonnage of mixed fluorspar-zinc ore. A shaft was sunk in 1943, and in March 1944 the mine was in daily production.

GEOLOGY AND ORE DEPOSITS

Minerva ore deposits at present mined consist of flat-bedded, lenticular replacements of the upper Renault limestones immediately below the Bethel sandstone, which constitutes the roof of the mine workings.

The stratigraphic position of the Renault limestone is shown in the following table:

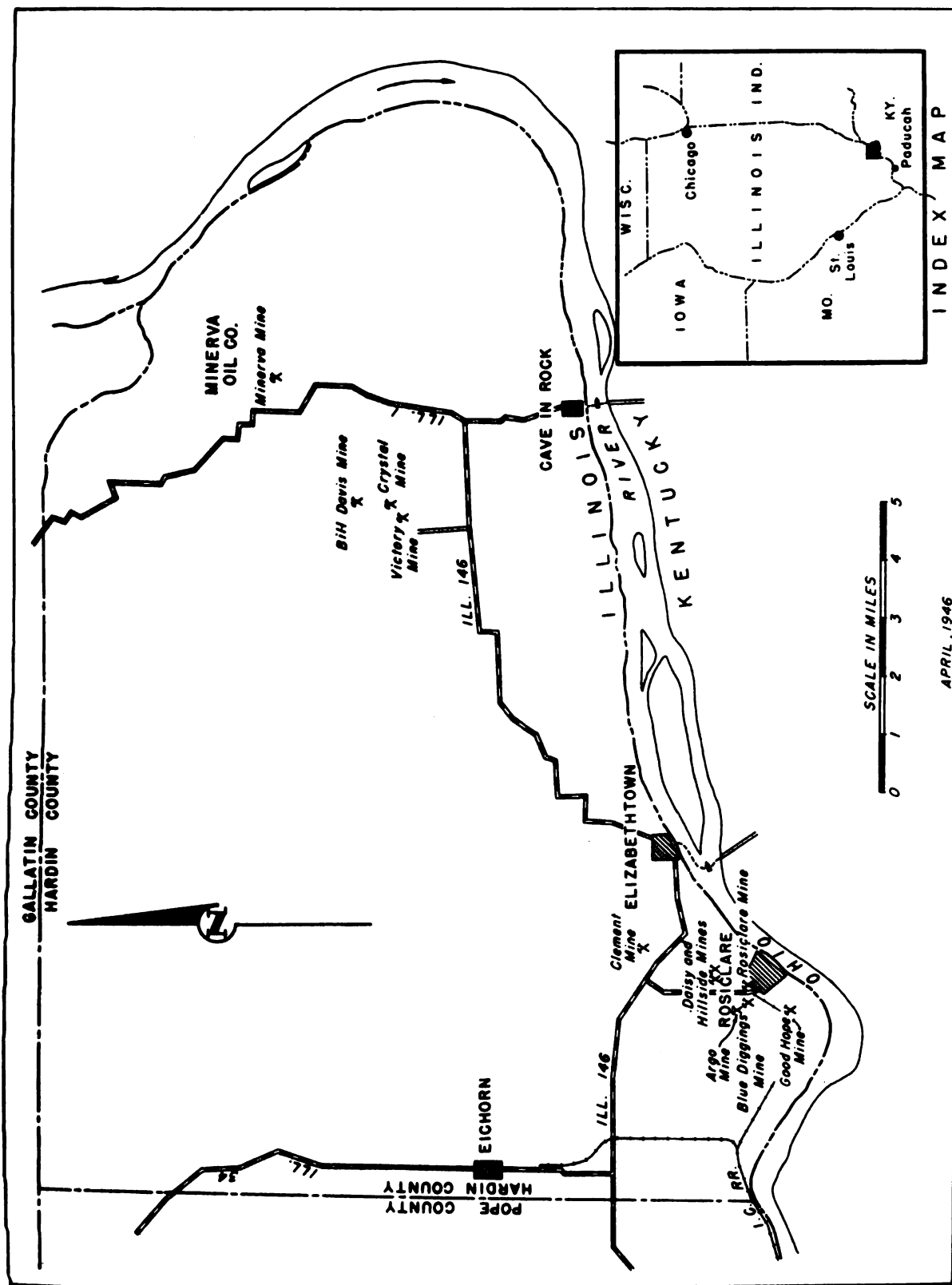


Figure 1. - Location map, Minerva mine.

	<u>Thickness, feet</u>
Mississippian series:	
Chester group:	
Cypress-Bethel sandstone.....	225+
Renault limestone and shale....	50+
Iowa group:	
St. Genevieve limestone:	
Levias limestone.....	25+
Rosiclare sandstone.....	25+
Fredonia limestone.....	180+
St. Louis limestone.....	?

The major structural control of the Cave-in-Rock district is the north-easterly trending Peter's Creek fault, which marks the northwestern boundary of the district and which, to the present time, has produced no commercial ore bodies. The downthrow of the fault is on the northwest side.

All of the so far discovered replacement ore deposits of the district lie in a zone about 1-1/2 miles wide on the southeast side of the Peter's Creek fault and appear to be related, genetically, to a series of very minor faults roughly parallel to the major fault.

The sedimentary bedrock formations of the district are nearly horizontal except where local faulting has produced sharp flexures. Minor folds with associated fissures seem to have localized ore deposition.

No igneous rocks have been found in the district.

In the Minerva Oil Co.'s Mine No. 1, fluor spar and sphalerite are the predominant ore minerals, but the deposits contain varying amounts of calcite and barite and minor occurrences of pyrite, galena, chalcopryite, aragonite, and quartz. A couple of pockets of galena have been found.

Ore bodies are lense-shaped, range in width from 30 to as much as 300 feet, range in thickness from 3 to 20 feet, with an average of about 9-1/2 feet, and are of undetermined length. The trend of the ore bodies is mainly N. 55° E. and they have a general dip of 3-1/2° to the northeast in beds dipping 7° northward. The Bethel sandstone roof is not too strong and in places necessitates leaving large pillars and about a 2-1/2-foot layer of ore overhead.

PROSPECTING AND EXPLORATION

Initial prospecting was by churn drilling and a combination of diamond core and churn drilling. However, very little diamond core drilling was used because of the great thickness of hard sandstones overlaying probable ore horizons. In 10 holes, cores by diamond drilling were taken through 2-inch tubing after a churn drill had been used to reach the ore horizon. The experiment was expensive and not too informative. In two churn-drill holes a cable tool coring bit made by Baker Oil Tool Co. was used to take 3-inch cores in limestone, but in the ore, which is softer

and more friable, core recovery was poor. As both cuttings and core were recovered, however, its application was interesting. A Baker cable-tool coring outfit is a tool for obtaining a core from churn drilling. The tool consists of two principal parts - an outer drilling barrel with bit attached and an inner core-retaining tube. In operation, the inner barrel rests on bottom, whereas the outer or drilling barrel is operated with a slightly slower motion and a shorter stroke than is used for regular drilling. The core retaining tube follows down over the core which is being cut by the drilling barrel and an accurate cross-section of all formations enters the barrel and is retained and recovered (fig. 2).

In the prospecting and exploratory stages and before a shaft was sunk, over 100 holes were drilled to partly outline two ore bodies approximately 500 feet apart and parallel. One, the west ore body, had a proven length of nearly a mile, whereas the other, the east ore body, had a known length of 3,500 feet. Grade of ore and approximate tonnages were determined from drill-hole data.

Virtually all surface drilling, whether for prospecting or to extend known ore bodies, is now done by churn drill. The company usually employs one or two contract drills operating two shifts a day. The usual practice is to sample at 5-foot intervals while in barren formations. Contact with ore is recognized by softening, at which time the hole is thoroughly cleaned and the sampling interval lessened to 2-1/2 feet.

Underground diamond core drilling into the walls and floors of mined-out portions of the stopes has been used to determine the existence of another parallel deposit and several obscured offshoot bodies. This method of prospecting has proven cheaper than churn drilling when the hole length does not exceed 300 feet. Horizontal diamond-drill holes were all in possible ore-bearing limestone and perpendicular to the fractures. Vertical diamond-drill holes tested formations 100 to 150 feet below stopes. The company uses underground diamond core drilling from time to time, but churn drilling from surface is the preferred method of exploration at substantial distance from the mine faces.

SAMPLING AND ESTIMATION OF RESERVES

No attempt is made to sample the faces of the underground workings. A grab sample from each 5-car train of ore arriving at the shaft bottom accumulated for a specified period and representing a certain tonnage is taken to determine the mine's current average grade of ore and to check the mill heads.

Ore-reserve estimates are revised annually by using data from drill holes and stope maps.

METHODS OF DEVELOPMENT AND MINING

Initial development was by a vertical shaft sunk in barren rock between the two ore bodies. A haulage level was then driven 30 feet under, and raises were made to the ore. There is one 45° access raise to each ore body. Ore

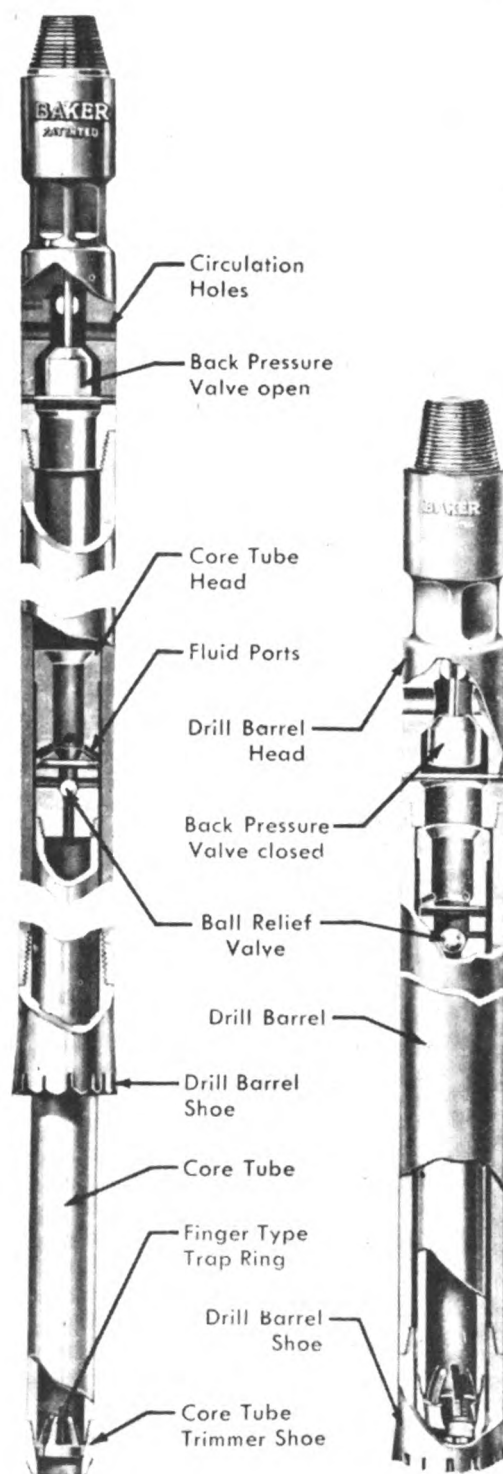


Figure 2. - Baker cable tool core barrel.

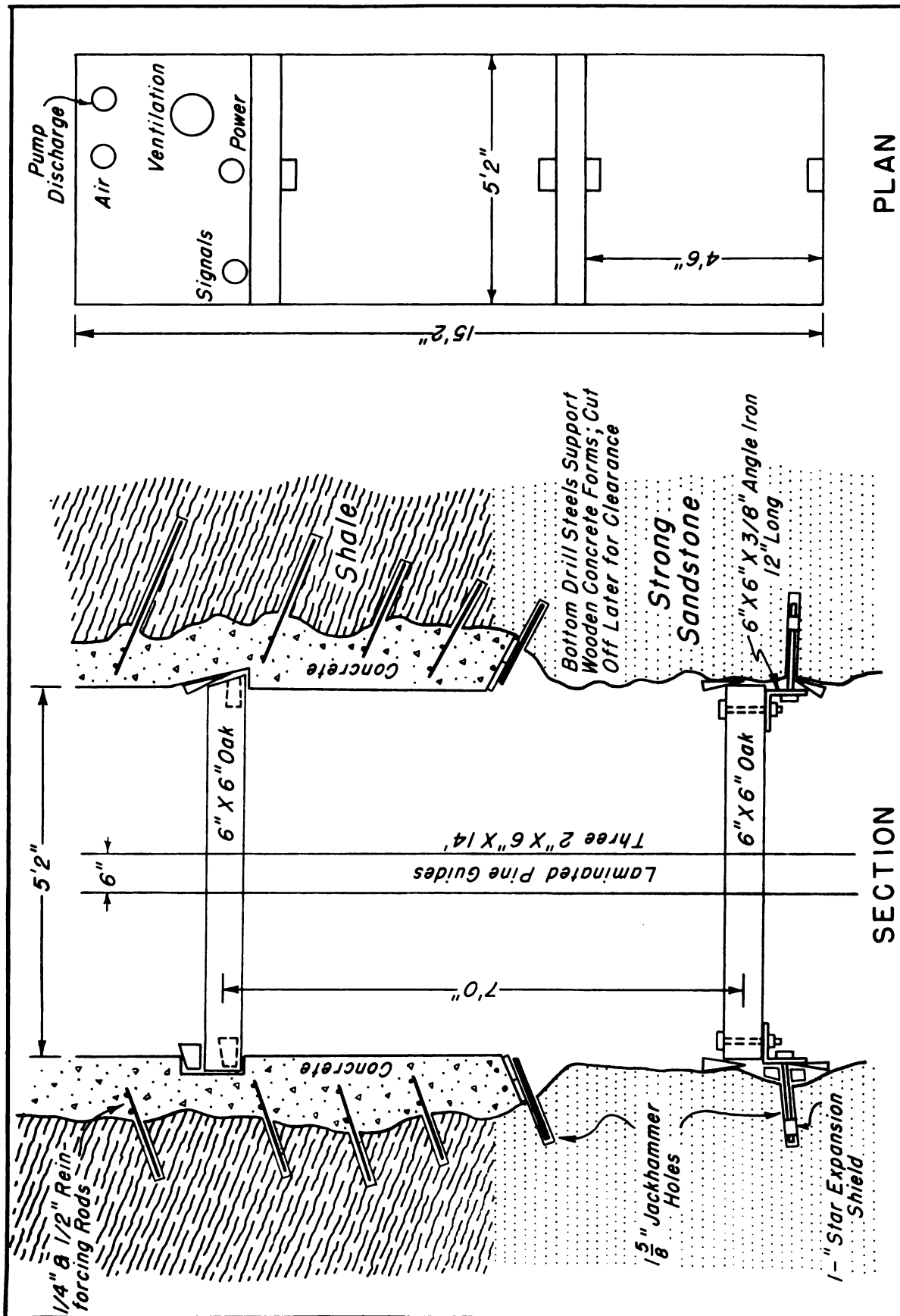


Figure 3. - Shaft concreting in weak formation.

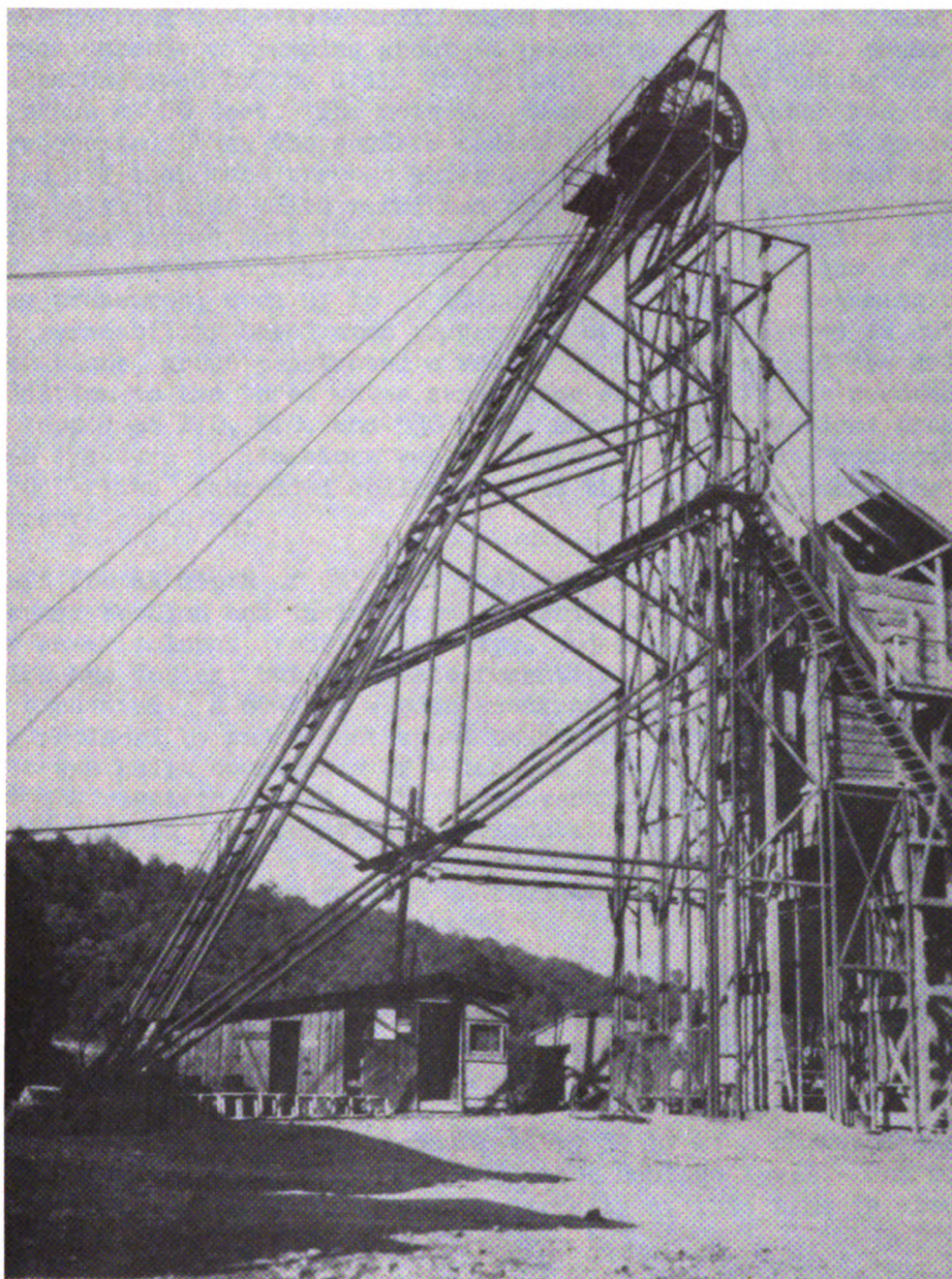


Figure 4. - Steel head frame. (Courtesy of Minerva Oil Co.)

passes are made at 100- to 150-foot intervals and provide substantial storage.

Before sinking the shaft, it was necessary to grout several pervious strata of sedimentary rocks overlying the ore level. This was done by means of a Bucyrus-Armstrong cable tool drill and a Dowell standard oil-field cementing truck capable of pumping grout at pressures up to 3,000 pounds. Bed rock was encountered by the drill at 15 feet, and 7-inch casing was then cemented in place at 20 feet. The hole was deepened until water-bearing formations were penetrated; then the surface casing was equipped with a Bradenhead, which admitted a 2-inch tube through which cement could be delivered to the bottom of the hole; a side valve permitted circulation in the hole. A slurry of neat cement was pumped into the hole and the grout was allowed to set under 30 pounds of pressure for 8 hours. Usually, at least three stages of grouting at increasing pressures, even up to 1,500 pounds, were made. Assuming uniform porosity and permeability based upon percentage of voids observed in outtings from the formations, grout penetrated a radius of 25 feet around the drill hole. In addition to the three water sands near surface, it was necessary to grout those topped at 270, 420, and 530 feet, making six elevations grouted. Only one open fracture in limestone was encountered at 70 feet, necessitating the use of "Gel-flake" (shredded cellophane) in the cement to gorge the crevice for high-pressure grouting.

The shaft (total depth of 645 feet including a 10-foot sump) is 5 by 15 feet in cross section and includes two hoisting compartments and a compartment for water columns, ventilation pipe, and manway (fig. 3). No timber was used below the collar, but all shale formations were concreted immediately after being excavated. A 60-foot wooden headframe was used for sinking. Later it was replaced by an 80-foot steel headframe that is unique and unusual (fig. 4). It was built completely of 4-inch, A.P.I., oil-field, rotary-drill pipe, all joints electric-welded. The three vertical sections were built on the ground and hoisted into position. Horizontal bracing was then electric-welded. By the use of large (7-foot) sheave wheels, bearing pedestals were supported by headframe members resting on foundations at the side of the shaft instead of on bridge work across the shaft.

The hoist used is a Lambert electric powered by a 150-horsepower motor. It has a 6-foot cylindrical drum with 54-inch face, on which are spooled two 1-inch improved plow-steel ropes, one spooling over and the other under, thereby hoisting in balance.

Rock is hoisted in skips that measure 46 by 54 by 27 inches and are of 2-ton capacity. Hoisting is from the 630-foot haulage level. One mine car is hoisted to one skip load. Mine-car capacity at this time is about 1.7 dry tons.

The next step in the initial development was driving 8 by 8 foot drifts, untimbered, except for intervals of bad ground, under and between the two parallel ore bodies. The ore bodies have a general dip of $3\frac{1}{2}^{\circ}$ to the northeast; therefore, about 500 feet from the shaft the north haulage drift was actually being driven into the west ore body. The haulage level will cut the east ore body at a distance of 1,500 feet. Development drifting was done with CF-79 Gardner-Denver wet automatic drifters using 1-1/8 inch, lug-shanked,

hollow drill steel and 4-point jack bits. Drift rounds were of the pyramid-cut pattern of 18 to 19 holes. Forty percent gelatin dynamite detonated with No. 6 electric blasting caps was used. A pattern of typical drift round and firing order for the holes is shown in figure 5. Mucking was done with a 12B Eimco mechanical loader into Koppel side dump cars having a capacity of 1.4 tons. These cars were later enlarged to contain 1.7 tons.

The final stage in developing the ore bodies was the driving of 6 by 6 foot raises on approximately 100- to 150-foot centers from the haulage level into the ore bodies. Nearest the shaft, the ore bodies were about 57 feet above the level, but to the northeast the ore bodies and the haulage level eventually meet, as shown in figure 6. One inclined raise was equipped with manway, tool slide, and air and water lines as well as electric conduit. Chutes were fitted with bottom-closing, pneumatically operated gates, as shown in figure 7.

Development now is entirely by drill holes and consists of delimiting the ore bodies ahead of mining operations.

Mining is by open stope with pillars, as in southeast and southwest Missouri. Two ore bodies are being worked, known as the east and west ore bodies. They are 600 feet apart and are in the Renault limestone formation approximately 630 feet below surface. No ore face less than 6 feet is being mined. Drilling has indicated the west ore body to be possibly a mile in length, and the east ore body now appears to be 3,500 feet long. Slightly different methods are used in the two stopes.

In the east stope, drilling was done recently by two standard, light-weight, Gardner-Denver CF-79, automatic drifters mounted on a caterpillar-tread steel drill jumbo (fig. 8). Built by General Steel Products Co. of Joplin, Mo., the jumbo was a Model 30 caterpillar tractor with its engine converted to use compressed air. Drilling in the west stope was done by the same type of drilling machines mounted on the conventional double-screw column and arm. All machines used 1-1/8-inch, round, lug-shanked drill steel with 4-point jack bits. Beginning in early 1948, the company purchased an Eagle-Picher type jumbo driven by two 5-horsepower air motors. Both jumbos were then fitted with single D-505 Ingersoll drifters mounted on 11-foot wagon-drill sashes with air-motor chain drives. A change was then made to 1-1/4-inch steel, using lengths of 7 and 13 feet for drilling average slab-hole depths of 12 feet. This machine, at its greater drilling speed and fewer steel changes and better maneuverability, made possible approximately double the hole footage that could be produced by a 2-man drill crew under favorable working conditions. Areas of low roof and small rooms and drifts must still be drilled with the column-mounted smaller drifters, however. The change to 1-1/4-inch steel from 1-1/8 has substantially reduced drill steel breakage. Chucks on the older Gardner-Denver machines were changed, as supplies of the smaller steel were exhausted. "Slab" rounds of 12 to 14 holes about 12 feet in depth are used in the stope faces (fig. 9). Gelex No. 2 dynamite in 1-1/4 by 8 inch sticks and standard safety fuse with No. 6 caps for detonation are used. Approximately 1-1/2 boxes (75 pounds) of dynamite is necessary in the usual round of 14 holes to break about 55 to 60 tons of ore. The usual practice is to shoot three or four rounds before beginning mucking. Two 600-c.f.m.,

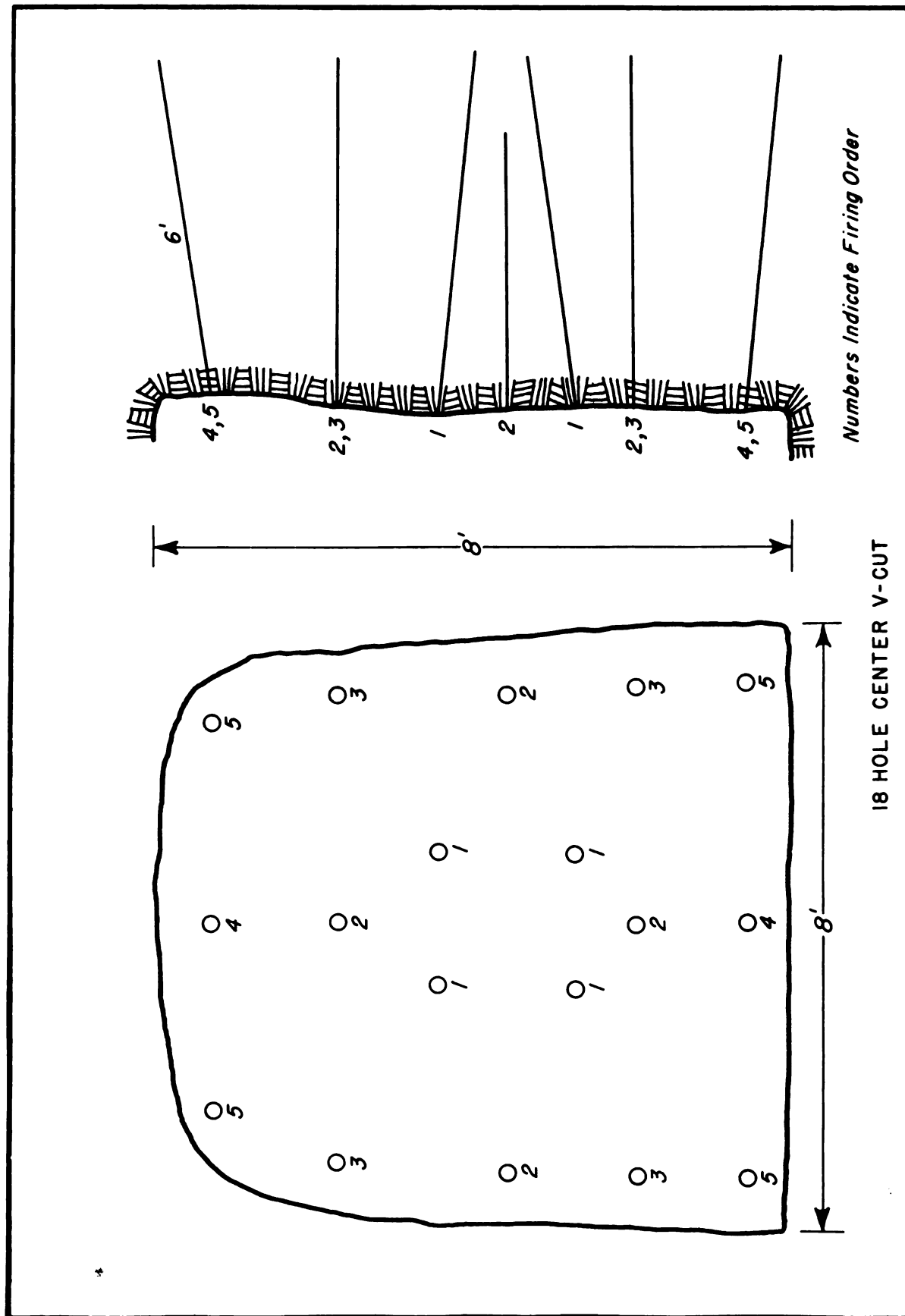


Figure 5. - Typical drift round.

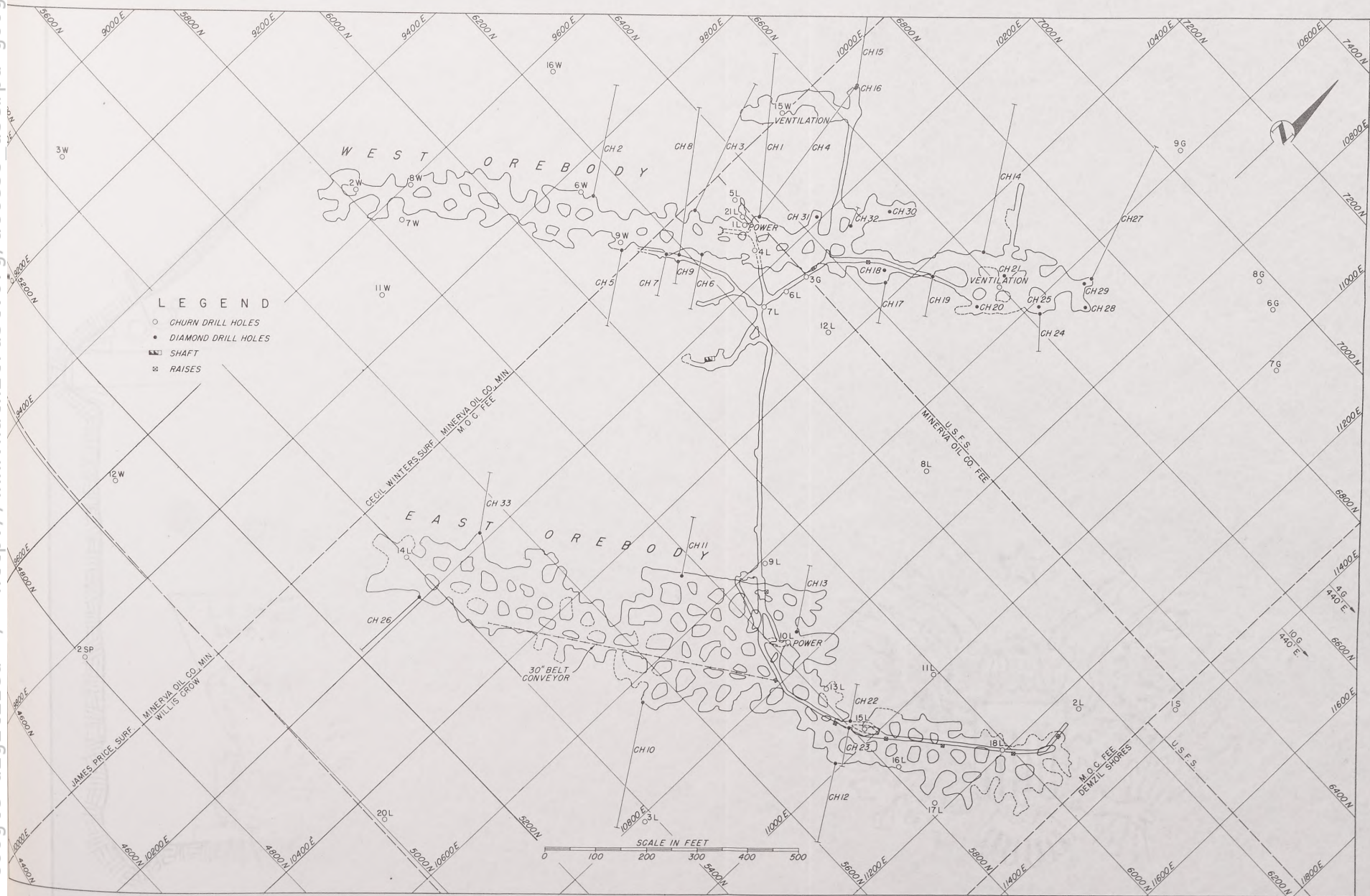


Figure 6. - Mine workings and drilling.

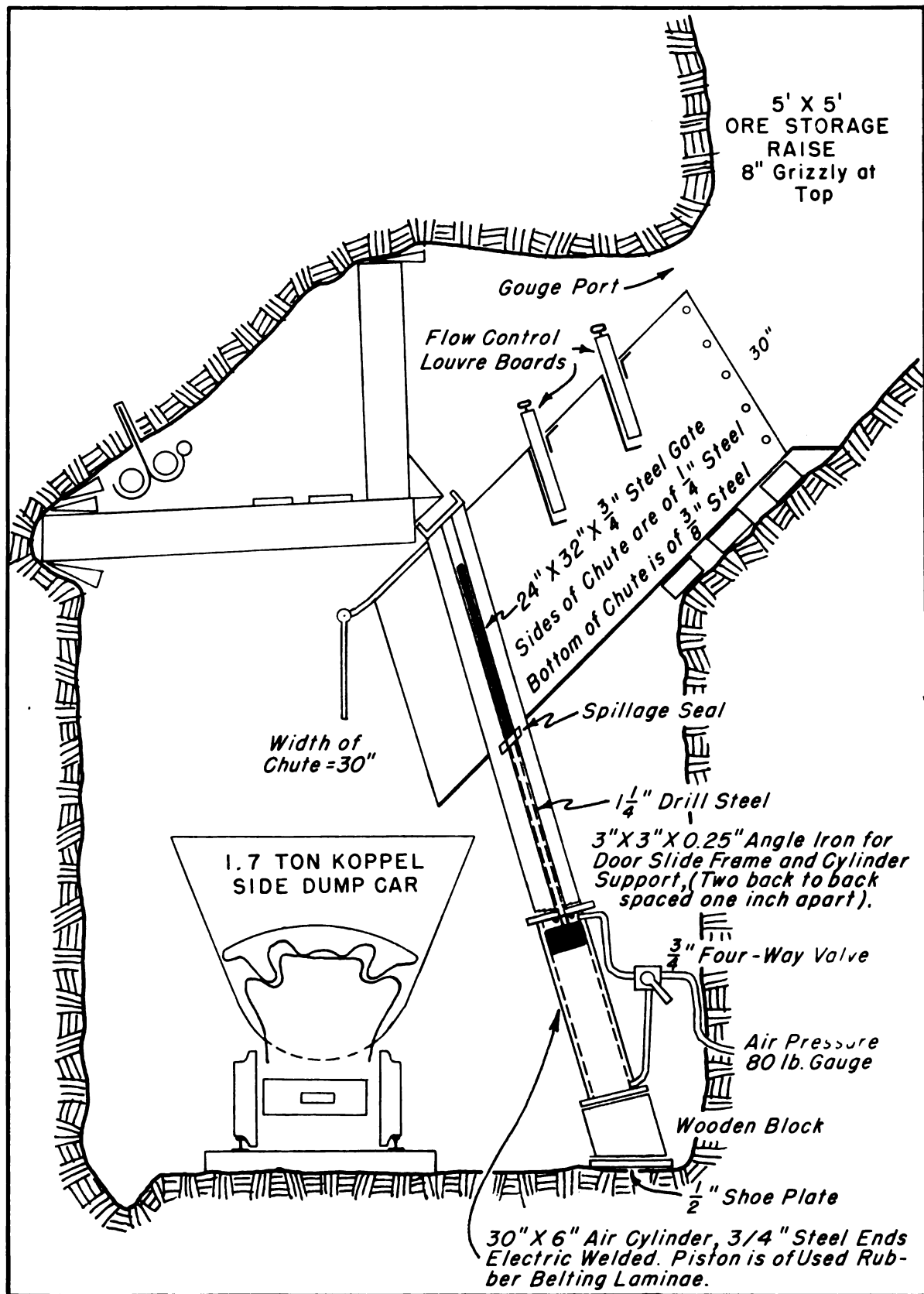


Figure 7. - Pneumatic chute gate.

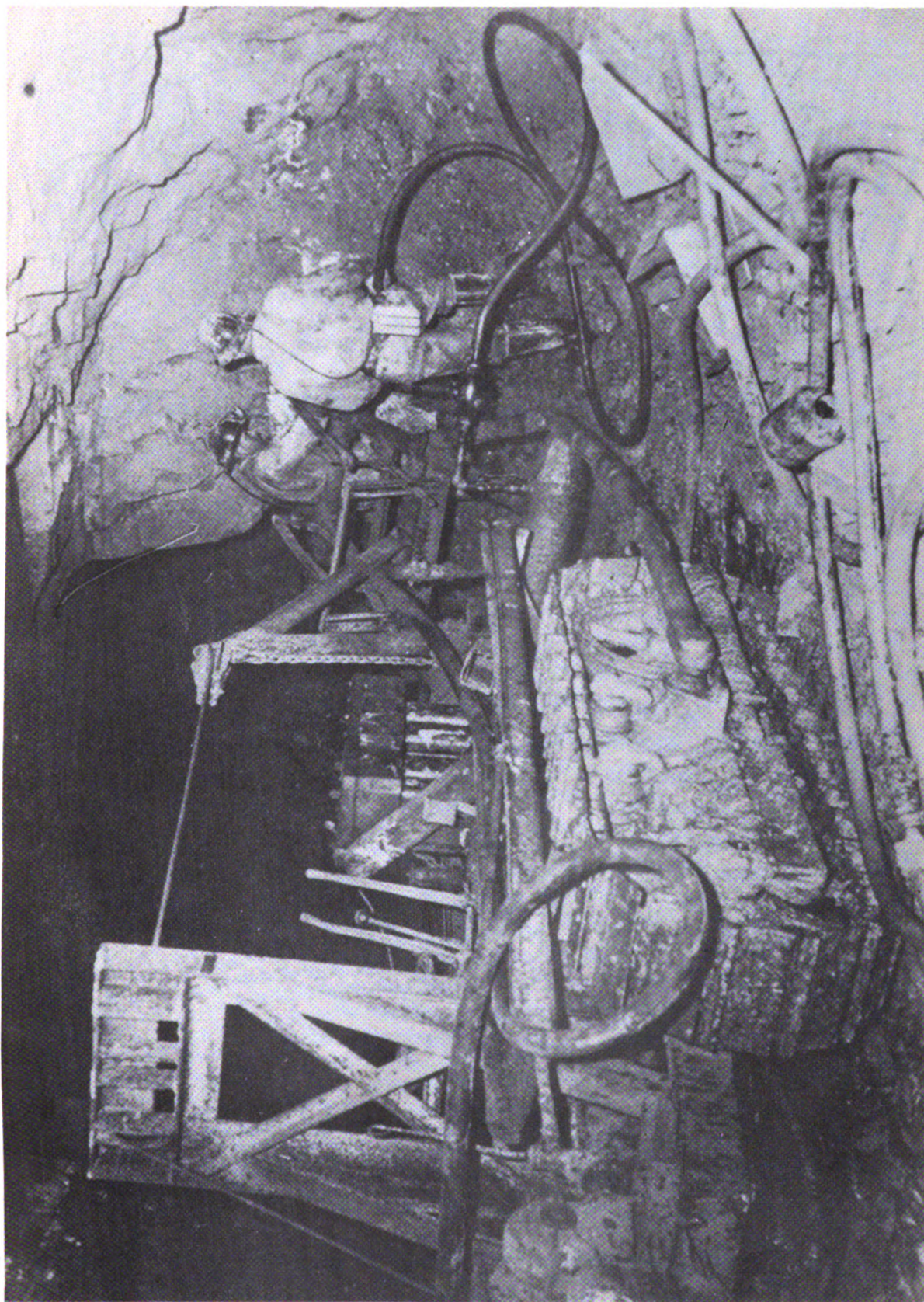
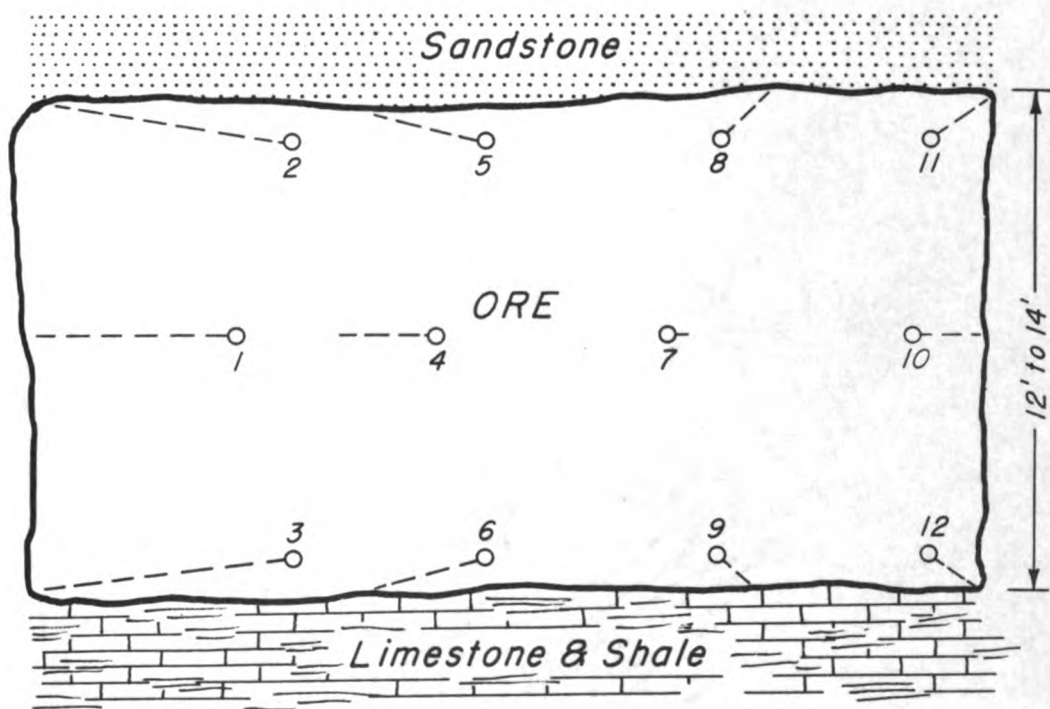
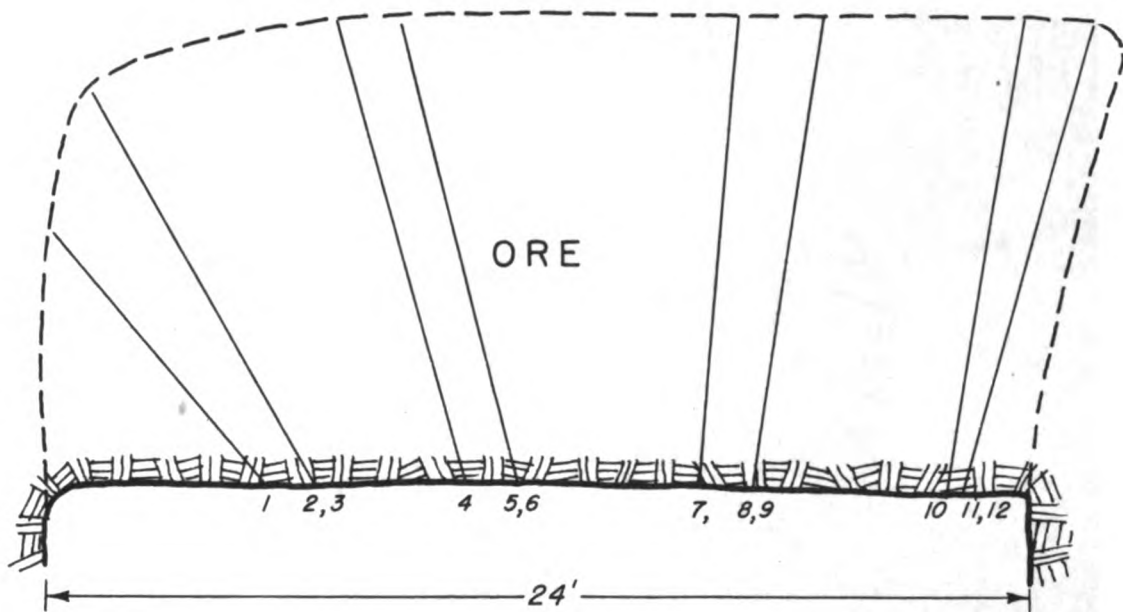


Figure 8. - Drill jumbo, east stope. (Courtesy of Minerva Oil Co.)



Numbers Indicate Firing Order

Figure 9. - Typical slab round in stope.



Figure 10. - Caterpillar-mounted scraper hoist. (Courtesy of Minerva Oil Co.)

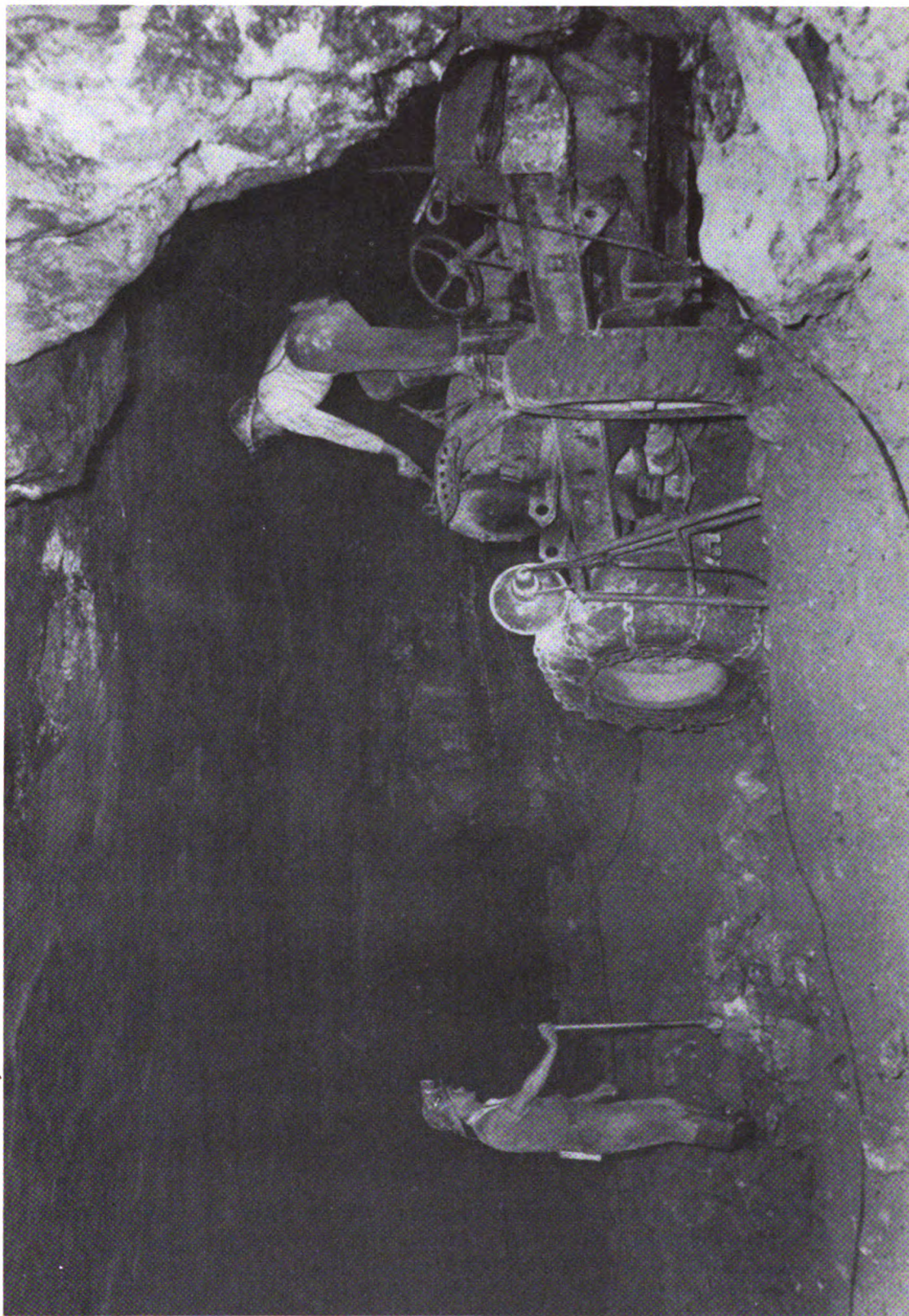


Figure 11. - Pneumatic tire-mounted scraper hoist. (Courtesy of Minerva Oil Co.)

I-R Imperial-type compressors on surface furnish compressed air for mine operations. Air pressure underground is maintained at 80 pounds.

The ore is loaded in the east stope by means of a caterpillar-mounted slusher unit powered by 7-1/2-horsepower motor for travel and a 20-horsepower, 3-drum, electric hoist pulling a 48-inch scraper, which slushes the ore into a rubber-tired truck having a capacity of 7 tons, which hauls the ore from the working face to a belt conveyor via a 48-inch belt feeder, which in turn conveys the ore to the transfer chute. The present loading method in the west stope differs slightly from that in the east stope, in that the ore at the face is scraped into a 5-ton-capacity mine car on rails, which is pulled by a double-drum hoist to the transfer raise (figs. 10 and 11). Faces in the west stope are at present about 250 feet from the transfer raise. Rubber-tired electric trucks will replace rail cars in stopes. Present production of the west stope is less than one-half that of the east stope and, with less efficient equipment, is used as a reserve working area.

Chutes are equipped with bottom-closing pneumatic gates, because the condition of the ore changes quickly from very wet to muddy to dry and from fine to very coarse. Figure 7 shows the construction of the gates. Ore is drawn into Koppel side-dump cars having a capacity of 1.7 tons. Five-car trains are hauled by two 3-1/2-ton Mancha Bearcat Model X10HP locomotive with duplicate batteries. At the shaft bottom the cars are spotted, two at a time, in front of the hoisting compartments by a 5-horsepower, Ingersoll-Rand, single-drum air tugger. This tugger also dumps the ore from the cars directly into the skips by hooking onto a side ring hitch on the car body. Ore is hoisted at the average rate of about 90 seconds per car.

Extraction in the east stope is about 60 percent because of the necessity of leaving large pillars and approximately 2-1/2 feet of ore in the back. This ore in the back, as well as two-thirds of the pillars, will be recovered eventually, so that final recovery will be 80 to 90 percent.

Cross-bedded sandstone roof in the east stope has given much dilution. In the west stope the same sandstone roof is very good, pillars are smaller and more widely spaced, and less timber is used. The mine operates one shift per day 6 days per week, and daily production is approximately 265 tons.

A third ore body, discovered by horizontal core drilling in 1946, was reached and crosscut by a 150-foot development drift in 1947. It is parallel and northwest of the west ore body, but only 500 feet of length along it has been proved. Intermittent production from it with the west-stope drilling and loading equipment was started in January 1948, with a status of a reserve working area in case of breakdown of facilities elsewhere in the mine.

Mine Drainage

The fluorspar ore bodies, because of their many water channels, are the source of virtually all of the mine water, which is made at the rate of about 150 gallons per minute and which is nearly constant in all seasons. A 300-foot development drift near the pump room, temporarily out of use, has been dammed and is used for a settling sump. After being drained by gravity to

this sump, the mine water is pumped through a 10-inch drill hole by an Oil Well Supply No. 8P, 5- by 8-inch, high-pressure, duplex pump driven by 50-horsepower electric motor. This pump is under automatic float control. In addition, there are two other standby pumps (centrifugal) for emergency use. A second and duplicate duplex pump is being installed at the shaft bottom. They are geared to pump 180 g.p.m. at a 700-foot head to the mill-water supply pond.

Ventilation

Fresh air from surface to the mine is supplied by means of 5-horsepower Buffalo portable blowers mounted over 6-inch drill holes, which force air into the stopes near the heading. As new drill holes are cut, these surface blowers are moved up. In the stope at the bottom of the drill hole, a 3-horsepower Jeffery booster fan picks up the air and forces it through 12-inch jute tubing to working faces that are remote from any drill hole. Two blowers ventilate each stope. The main shaft is upcast.

Power

Electric power is furnished by a 1,050 kva. Diesel plant. Through two drill holes, one near the east stope and one into the west stope, at the bottom of which are transformer stations, 2,300-volt, 3-phase, 60-cycle current is carried into the mine by armored lead-sheathed cable. The two stations are connected so that power may be fed to the entire mine through either entrance. Twenty-three hundred volts are carried into the mine, where it is reduced to 440 volts. Pumps use 2,300 volts and 440 volts. Tuggers, blowers, and electric truck use 440 volts. Haulageway lighting and signals are operated at 110 volts.

Safety

The mine does not have a regularly designated safety engineer. Foremen have general safety meetings monthly. There are only three active stopes at a time. The head drillman in each stope has instructions to "make his place safe" before commencing productive work. Inspection by shift boss and mine foreman, check the observance of this rule. Inspection by insurance engineers and state mine inspector with written recommendations are also effective. The reports of the safety committee also make foremen more safety conscious.

Miners safety meetings are held weekly. At the meetings there are talks by members of the mine staff and at times by representatives of the Bureau of Mines safety division and others. A 3-man safety committee inspects the entire plant monthly.

A safety record is kept posted on the company bulletin board. Frequency and severity are about average for Mississippi Valley underground mines.

Wages

All employees are nativeborn and most have lived all their lives within a few miles of the mine. A large percentage of the men are part-time farmers consequently absenteeism is high during planting and harvesting seasons. Company wage scale effective June 1, 1947, is as follows:

<u>Classification</u>	<u>Per hour</u>
Underground: Miner.....	\$ 1.10
Miner helper.....	1.00
Mucker.....	0.95
Underground mechanic.....	1.15
Hoistman.....	1.03
Shift leader.....	1.25
Surface: Engineer A.....	1.03
Carpenter A.....	1.08
Mechanic A.....	1.08
Mechanic helper.....	0.93
Mechanic B.....	1.03
Laborer, common.....	0.83
Working Foreman.....	1.13

Actual rates for 6-day week are $\frac{52}{48}$ of above.

CostsSummary of Costs in Units of Labor, Power, and Supplies

Minerva Oil Co. Mine No. 1
Tons of ore mined and hoisted: 1,329
Mining method: Room and pillar

Week of August 17, 1947

Mine
stoping

A. Labor (man-hours per ton):

Breaking (drilling and blasting).....	0.181
Mechanical loading (slusher).....	0.252
Timbering.....	0.036
Haulage and hoisting.....	0.216
Supervision.....	0.111
General.....	0.108
Man hours per ton.....	0.904
Average tons per man per shift.....	8.8
Labor, percent of total cost.....	52

B. Power and supplies

Explosives (lb. per ton)..... 1.31

Total power (kw. hr.), 24,080 @ .012/kw. hr. = \$288.96

	Percent
(1) Air compression.....	20
(2) Hoisting.....	25
(3) Pumping.....	30
(4) Ventilation.....	5
(5) Lighting.....	3
(6) Elec. loading machinery.....	17
(Other supplies in percentage of total power and supplies).....	25.8
Powder, supplies and power (percent of total cost) including machinery depreciation, surface shop services, etc.	48

Summary of costs

Minerva Oil Co. Mine No. 1

Week of August 17, 1947

Tons ore hoisted during period: 1,329

Mining method: Room and pillar

Underground cost per ton of ore hoisted

Item	(1) Labor	(2) Super- vision	(3) Air drills and steel	(4) Power hoisting etc.	(5) Explo- sives	(6) Tim- ber	(7) Sup- plies	(8) Total
Development..	0.322	0.059	0.029	0.010	0.102		0.091	0.613
Mining.....	1.242	0.105	0.143	0.070	0.214	0.002	0.127	1.903
Haulage.....	0.180	0.015		0.004			0.015	0.214
General un- derground expense....	0.108	0.005					0.008	0.121
Surface ex- pense di- rectly ap- plicable to underground work.....	0.101							0.101
Total....	1.953	0.184	0.172	0.084	0.316	0.002	0.241	2.952

In commenting on the above costs, Steinmesch remarks:

Operations commenced in March 1944. Entrance to and development of ore bodies has been an excessive but declining cost. In the summer of 1947, one 8 by 8-foot drift was being driven one shift per day in waste at a cost of more than 29¢ per ton of ore sent to mill. This appears unreasonable but will probably continue for some time.

The management has concentrated on increasing output per man by a close follow up of the weekly report of output from the stopes. Some progress has been made, but output of drills and loaders is far below machine capacity, and care of equipment leaves much to be desired.